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Report of the Interagency Space Reactor Standards Working Group

Space Reactor Standards Working Group
NASA's Office of Chief Engineer
NASA Headquarters, Washington DC

March 2022

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National Aeronautics and
Space Administration

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Nomenclature

ANS	American Nuclear Society
ANSI	American National Standards Institute
APL	Applied Physics Laboratory
ASFCMAN	Air Force Space Command Manual
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CFR	Code of Federal Regulations
CPG	Compliance Policy Guidance
CR	Contractor Report
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DOE	Department of Energy
DOS	Department of State
DOT	Department of Transportation
DRACO	Demonstration Rocket for Agile Cislunar Operations
EPA	Environmental Protection Ag
FAA	Federal Aviation Administration
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Agency
GSR	General Safety Requirements
HDBK	Handbook
HEU	Highly Enriched Uranium
IAEA	International Atomic Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
INSRB	Interagency Nuclear Safety Review Board
ISO	International Organization for Standardization
KSC	Kennedy Space Center
LWR	Light Water Reactor
MIL-STD	Military Standard
NASA	National Aeronautics and Space Administration
NCRP	National Council on Radiation Protection and Measurements
NPR	NASA Procedural Requirements
NRC	Nuclear Regulatory Commission
NSPM 20	National Security Presidential Memorandum 20
OMB	Office of Management and Budget
PLN	Plan
PRA	Probability Risk Assessment
RA	Risk Assessment
RG	Regulatory Guide
SMC	Space and Missile Systems Center
STD	Standard
SWG	Standards Working Group
TM	Technical Memorandum

Executive Summary

A U.S. governmental interagency space reactor standards working group (SWG) was convened in April 2021 with a memo from the NASA Chief Engineer, Ralph R. Roe, Jr. to address the limited standards and regulations in place specifically for space reactor design and safety. The convening memo requested support from the Standards Executives of six other federal agencies: Department of Defense (DOD), Department of Energy (DOE), Department of State (DOS), Department of Transportation (DOT), Environmental Protection Agency (EPA), and the Nuclear Regulatory Commission (NRC). The Standards Executives agreed to support a 6-month study to assess the need for consensus standards and identified SWG representatives from each agency.

The monthly meetings that occurred between July and December 2021 permitted steady progress by the SWG in reviewing existing standards, assessing Agency needs, specifying gaps that could be addressed by new standards, and prioritizing those gaps through consensus group deliberations. The SWG agreed that consensus standards have value and should be pursued for space reactors (Finding #1). The SWG performed an extensive review and compiled a list of relevant existing standards that should be a resource for future efforts (Finding #2). The group deliberations examined 42 separate needs submitted by the agencies that were consolidated to 11 high-level gaps. The prioritization process revealed some differences among the agencies about the state-of-knowledge and relative importance of several gaps. The SWG proposes that workshops be held among member agencies on those topics to resolve the differences in the perceived gap significance (Finding #3). The SWG recommended that three high-priority gaps be pursued through a consensus standards development process, as follows:

- Safety and Risk Analysis Methods for Space Reactors
- Testing Requirements for Space Reactors, including Facility Requirements
- Safe Operating Practices for Space Reactors

To implement this recommendation, the SWG also recommended that one of the agencies be identified as the "champion" (i.e., a designated lead) for each of the three gaps to develop a work plan to define the next steps for each gap (including expected cost and schedule) and to engage other agencies and the appropriate consensus standards body, as appropriate. Furthermore, the SWG recommended that National Aeronautics and Space Administration (NASA) should convene an interagency group periodically to review progress.

The gaps that were not prioritized for near-term action are still considered important and could be topics for future agency-level guidance documents or community-of-practice workshops. The SWG concluded that the standards development process would benefit from broad participation by government agencies, stakeholders, consensus body organizations, industry, and academia (Finding #4). The findings and recommendations were presented to the Agency Standards Executives in January 2022 where the SWG was commended for the thoroughness of the study and the cogent conclusions. The next steps were put in motion to establish "champion" agencies for each of the three gaps and engage the appropriate standards organizations.

1.0 Introduction

The past few years have seen a reinvigorated interest in proposals for nuclear fission surface power on the Moon and Mars, along with nuclear thermal or nuclear electric propulsion for Mars missions, deep space exploration, and other activities. Recent developments include a variety of different entities interested in space nuclear systems, accompanied by a high degree of collaboration developing among both government agencies and commercial entities, such as BWXT, General Atomics, Space Nuclear Power Corporation, and Ultra Safe Nuclear Corporation. Government agencies continue contract with the private sector to support government missions, while commercial interest in space is increasing rapidly in areas of *in situ* resource utilization, communications, and even space tourism.

The assortment of agencies and non-governmental entities potentially participating in the development of space fission reactor systems leads to differences in interests and development needs. Therefore, it is appropriate to consider whether consensus technical standards can guide future reactor development and provide consistency in the treatment of safety across different entities. To address this question, the National Aeronautics and Space Administration (NASA) Chief Engineer requested a standards working group (SWG) involving seven agencies to study whether consensus standards activities should be pursued. The seven agencies are Department of Defense (DOD), Department of Energy (DOE), Department of State (DOS), Department of Transportation (DOT), Environmental Protection Agency (EPA), NASA and the Nuclear Regulatory Commission (NRC) (see Appendix A). The primary tasking for the SWG was:

> *…complete a study to validate the need for such standards, address any concerns that you might have, and chart a path forward.*

The Standards Executives agreed to support a 6-month study and identified primary and alternate SWG representatives from each agency, as listed in Table 1. The DOT Standards Executive identified members from the Federal Aviation Administration (FAA). The SWG Chair and Co-chair were selected to be Lee Mason from NASA and Karl Garman from DOT/FAA, respectively. A primary and alternate Executive Secretary with relevant experience in space nuclear systems and consensus standards was identified to support SWG activities and manage logistics. Several ex-officio members participated in discussions as subject matter experts but did not participate in the voting.

Table 1. Space Reactor SWG Members and Standards Executives

Agency	**Primary**	**Alternate**	**Standards Executive**
DOD	Lauryn Williams	Cory Alford	Michael Heaphy
DOE	Tom Hiltz	Andy DeLapaz	Garrett Smith
DOS	Patte Metz	(No alternate)	Scott Clayton
DOT (FAA)	Karl Garman (Co-chair)	Glenn Rizner	Timothy Klein
EPA	Chris Hallam	Oleg Povetko	Elise Owen
NASA	Lee Mason (Chair)	Don Helton	Ralph R. Roe, Jr.
NRC	Tina Ghosh	Boyce Travis	Louise Lund
Exec. Secretary	Allen Camp	Andy Klein	
Ex Officio	Eric Mattessich, Tabitha Dodson, Danielle Montecalvo, David Mayo		

The initial meeting of the SWG was held on 19 July 2021 when the study approach was introduced, and the members provided feedback on the proposed work plan. Monthly meetings were held through 16 December 2021 in preparation for a final presentation to the agency Standards Executives on 20 January 2022 (see Appendix B). The meetings were conducted using a consensus-body, decision-making process, with each agency having an equal vote on motions and debates. Meeting minutes were prepared by the Executive Secretary and routed among the working group members for approval. The SWG made steady progress during the six-month study by reviewing existing standards, assessing agency needs, specifying gaps that could be addressed by new standards, and prioritizing those gaps through group deliberations.

This report is the result of this effort. Its scope is limited to space nuclear fission reactors, and thus it explicitly does not address radioisotope power or heating systems, nor does it address fusion or hybrid reactors. Further, this discussion is not tied to any currently planned missions. Standards take time to develop and should not be on any critical path for a mission. If and when any standards are approved, then subsequent missions could implement them.

2.0 Role of Consensus Technical Standards

With a variety of organizations considering the use of space reactors and few space reactor-specific processes currently in place, it is appropriate to consider how consensus standards may be utilized in a variety of ways, including reactor design, safety analysis, and operations. For example, National Security Presidential Memorandum 20 (NSPM-20) outlines the steps for separate launch approval chains, depending on the sponsoring agency or commercial entity requesting approval.[1] For government launches of space fission reactors, the head of the sponsoring agency approves the launch unless it falls in a category requiring White House approval, e.g., a fission reactor using highly enriched uranium (HEU). The sponsoring agency shall request of the NASA Administrator that the Interagency Nuclear Safety Review Board (INSRB) perform a review. For commercial launches, the DOT has approval authority. NSPM-20 allows DOT to request assistance from other agencies in reviewing the safety analysis or to request an INSRB review.

One of the goals of NSPM-20 was to reduce the uncertainty in the launch approval processes for the benefit of mission planners who choose to use nuclear systems. However, NSPM-20 does not specify how the supporting analyses are to be carried out. The development of consensus technical standards can alleviate this problem, and further the goals of NSPM-20, by ensuring that the safety assessments performed by the system developers will ultimately be accepted by the sponsoring or regulating agency. Such standards will also help mission planners more accurately predict costs associated with safety assessment and launch approval.

Nuclear power is unique in that, when an accident occurs, the entire nuclear industry experiences long-term consequences, even in cases with minimal public radiological health impact, such as the accidents at Three Mile Island or the Fukushima Daiichi nuclear power plant. In that sense, each agency has a stake in the nuclear activities of other agencies. In addition, there are a number of areas where one agency or commercial entity may leverage the capabilities of another, including test facilities, fuel and component manufacturing, and launch facilities. Such collaboration could be simplified and can expedite the process if all entities work toward similar standards. Therefore, it is advantageous to bring together a broad range of nuclear experts to ensure that both government and commercial entities use common best practices in safety design and risk assessment.

Office of Management and Budget (OMB) Circular A-119 directs agencies to “use standards developed or adopted by voluntary consensus standards bodies rather than government-unique standards, except where inconsistent with applicable law or otherwise impractical.”[2] Each agency has appointed a senior executive to coordinate standards activities within the agency. Memorandum M-12-08, *Principles for Federal Engagement in Standards Activities to Address National Priorities*, specifies objectives for federal participation in standards activities.[3] While not addressed in detail in this report, the standards activities proposed are consistent with those objectives.

3.0 Relevant Available Standards

Dozens of consensus technical standards exist for terrestrial nuclear systems and handling of nuclear materials that have been developed by the American Nuclear Society (ANS), the American Society of Mechanical Engineers (ASME), the Institute of Electrical and Electronics Engineers (IEEE), American Society for Testing and Materials (ASTM) International, and others over several decades. These standards address topics ranging from materials and structures to reactor design and risk analysis methods and operations. In addition, there are many internal standards and guides produced by government agencies dealing with space launch and operations, nuclear issues, radiological preparedness and response, control of radiological air emissions, and used fuel management. SWG members provided lists of relevant documents from each agency. These lists will be made available to standards bodies as useful reference material. A summary of some of the more relevant documents is contained in Appendix C.

It is neither practical nor appropriate to reproduce this same set of standards for space systems. While the standards for terrestrial reactors contain much useful information, the standards were not written for space systems and, in many cases, internal agency standards are sufficient to address particular safety issues. The foundation for potential new standards may lie in the techniques previously developed by the DOE and its laboratories for launch approval of radioisotope systems and the design criteria developed by the NRC and DOE for terrestrial nuclear systems. However, those techniques (i.e., the details underlying these foundations) will need to be reviewed and may need modification to address aspects of space fission reactors, owing to the very different constraints for which they will be designed and operated, e.g., minimizing of payload weight, heat rejection in a vacuum, NSPM-20’s potential radiological accident probabilities and consequences, and differing accident environments, when addressing inadvertent criticality.

4.0 Assessing Agency Needs for Additional Guidance

Each of the seven agencies participating have varying roles in the lifecycle of a space fission reactor system. These roles include design, development, testing, transportation, licensing, certification, launch approval, protection of human health and the environment, launch site management, reactor operations, and ultimate disposal. Some agencies have multiple roles, depending on the particular mission. Each agency was asked to provide a list of potential standards needs, reflecting the perspectives of the agency providing them. These needs mostly fall into two categories: process needs and specific technical needs, with the latter proposed at various levels of detail. These needs were then grouped into high-level needs for further consideration by the SWG. The SWG identified a list of 42 potential needs that could be addressed by consensus standards. This list was consolidated into the top 11 needs and identified as the most pressing needs. The

SWG decided that some needs should be combined with others in the list before further consideration and prioritization began. The high-level needs are the alphabetical items below, and the bullets reflect the specific needs identified by the agencies.

a. Safety Design Process for Space Nuclear Reactors – the factors that need to be considered and addressed in a new space reactor design
   - Process-focused materials that are consistent with the other agencies that are involved

b. General Design Criteria for Space Nuclear Reactors – specific design requirements that all space reactors should meet
   - Mission performance criteria to justify use of HEU in space reactors
   - Definition of environments for which space reactors and reactor fuel must remain subcritical
   - Design reactivity margins for achieving criticality in space reactors
   - Design reactivity margins for maintaining subcriticality in space reactors
   - Criteria for inadvertent criticality
   - Methods to verify design life of space reactors
   - Minimum factors of safety for space reactor pressure vessels
   - Criteria for space reactor configuration during reentry (i.e., how to evaluate burnup and radionuclide inventory versus intact versus scattered reentry choices)
   - Resiliency
   - Criteria for when space reactors can be started up

c. Storage of Test and Flight Space Reactors – safety requirements for storing assembled or disassembled reactors at test sites, launch facilities and other locations
   - Criteria for storing test and flight space reactors
   - Transportation/storage of nuclear equipment on ground

d. Transportation of Test and Flight Space Reactors – safety requirements for transporting space reactors and nuclear equipment between and within facilities
   - Transportation/storage of nuclear equipment on ground
   - Criteria for transporting test and flight space reactors
   - Transportation standards for transportable reactors

e. Testing Requirements for Space Reactors – ground test requirements for new reactors prior to their use in space
   - Pre-flight verification testing standards for flight space reactors
   - Ground nuclear testing standards to qualify space reactor designs
   - Testing standards for factory-built systems
   - Space reactor testing requirements different from ground reactors

f. Facility Requirements for Testing – requirements for facilities to appropriately simulate anticipated environments
   - Criteria for impacts of ground safety systems on space reactor testing, including impacts on the goal of test-as-you-fly

- Requirements for propulsion tests (i.e., how to meet federal public health and environmental regulatory requirements)
- Simulation of space environments

g. Flight Certification or Licensing Process Requirements – requirements for launch safety and integration with launch and spacecraft systems *(Note that the terms 'certification' and 'licensing' often take on specific meanings, which vary between departments and agencies. In this document, these terms are used generally and not precisely, and should not be confused with specific definitions within any particular organization.)*

- Process-focused materials that are consistent with the other agencies that are involved
- Launch safety
- Flight certification (i.e., how to certify and how to treat nuclear payloads)

h. Safety and Risk Analysis Methods – requirements for risk analysis methods for performing NSPM-20 and related calculations

- Methods to calculate the potential accident probabilities versus maximum dose levels stipulated in NSPM-20
- Processes to analyze other aspects of launch authorization
- Methods for analyzing risks from inadvertent reentry

i. Methods to Calculate Radiation Doses from Space Reactors – requirements for assessing astronaut safety and shielding needs

- Methods to account for operating reactor systems on crew dose assessments (shielding and doses from other sources)

j. Safe Operating Practices for Space Reactors – requirements for operating reactors during all planned operational phases

- Fault-tolerance strategies for space reactor startup and shutdown
- Considerations for space reactor operational controls (i.e., how to implement autonomous and manual controls)
- Instrumentation and telemetric data rate expectations for space reactors
- Operating guidance for nuclear systems in space
- Guidance for proximity operations and on-orbit servicing
- Planetary protection issues
- Resiliency

k. Decommissioning and Disposal of Space Reactors – requirements for safe end of life decommissioning and disposal

- Process focused materials that are consistent with the other agencies that are involved
- Decommissioning guidance for systems in space
- Environmental contamination criteria for space disposal
- Methods to comply with Space Policy Directive 6 (e.g., sufficiently high orbit and sufficient radioactive decay)[4]
- Interim storage and ultimate disposal of ground test reactors and used fuel

The needs identified above are not sufficiently met for space reactors by available guidance/standards and are therefore considered to be gaps. All gaps need not be addressed by consensus technical standards. Therefore, criteria were developed for determining which gaps would best be addressed by consensus technical standards and how to prioritize them. In transitioning from needs to gaps, the SWG also translated the alphabetically identified needs into the corresponding numerical gaps, as identified in Table 2 (Section 6.0).

5.0 Criteria for Prioritizing Standards Gaps

The SWG developed a set of criteria for evaluating gaps to determine whether each was appropriate for future consideration by the SWG and, if so, how to prioritize them. Four required criteria were identified. If an identified gap did not meet any of those criteria, it was removed from further consideration. The SWG identified seven desired criteria to determine relative priorities of each gap. These are discussed further below.

a. Required Criteria

1. The gap applies to multiple agencies.

   If the gap applies to only a single agency, then it could potentially be addressed by internal agency standards and guides.

2. The gap can be addressed by a standard.

   In some cases, the gap may be dominated by policy issues. In other cases, the gap may be ill-defined or rapidly evolving such that a standard is not appropriate.

3. An existing standard is not available to all agencies to meet the gap.

   Existing standards should not be duplicated by this effort. No cases were identified where existing standards completely filled the identified gap.

4. The gap is associated with space fission reactor design or safety.

   This criterion was used to limit the scope of the activity. Radioisotope or exotic power systems were excluded, along with issues not related to design or safety, such as manufacturing, economics, or project management.

b. Desired Criteria

1. A standard would reduce costs and/or delays in the approval process.

   Successful standards tend to be those where there is an incentive for their use. Done properly, a standard can resolve controversial issues and reduce uncertainty in the approval process.

2. A standard would result in more consistent treatment of nuclear safety across agencies.

   Public health and safety should be independent of the government agency involved. Consistency can help prevent designers from “shopping” their ideas with different agencies looking for the easiest approval process.

3. A new standard may help resolve conflicts among existing standards.

Where different agencies may be involved in design, launch and operation of a space reactor, it is possible that different rules may come into conflict. Consensus standards can help eliminate those conflicts.

4. The gap is not technology specific.

In the future, detailed technology-specific standards may be developed. However, such standards are premature at this time, and the development of standards should not favor a particular technology during this early development phase.

5. The gap does not favor a particular designer or contractor, including government sponsored versus commercial.

Standards should not be developed that would tend to favor a particular organization over others.

6. The technical basis for a standard exists.

Standards are often written based on long-standing practice and experience. This is not the case for space reactors. However, expertise exists in the design and safety analysis of nuclear space systems, including reactors. In cases where expertise is limited, standards are sometimes developed for trial use, and endorsed at a later time for widespread use. In some cases, there may be existing standards that can be modified for use with space reactors. This criterion assesses whether there is enough technical expertise and background information available to proceed.

7. The standard can be completed in a reasonable time.

Standards are often a multi-year process. If a standards activity cannot be defined on a schedule that is reasonable given the need, then the standard should not be pursued.

6.0 Results of Prioritization

The criteria above were used by each agency to prioritize the identified gaps. The criteria were applied subjectively by each agency, and no particular weighting system was assumed. After an initial round of ranking, the SWG discussed the gaps and how the criteria were applied. The SWG then prioritized the identified gaps into High, Medium, and Low categories. High-Priority Gaps have a strong possibility for consideration to move on to standard development. Medium-Priority Gaps could be moved on to consensus standard development if they become more fully established, but with a significantly lower importance at this time. Low-Priority Gaps should not be considered as part of this effort to progress into a standard development process at this time but could be important topics for consideration by individual agencies through their own standards and workbook development processes. It is important to note here that where a particular gap falls on the list currently is not a reflection of its potential importance. The SWG was not tasked with creating broad judgements, but rather was focused on whether any gap is sufficiently important to be recommended to a consensus standard committee.

Summary of SWG discussions: The following is a summary of the SWG discussions and conclusions on the final gaps.

Following the identification of the 11 primary gaps, discussion centered on reducing the number of gaps for final consideration by combining similar gaps with others.

The three gaps that were combined with others were:

- Gap #4 – Transportation of Test and Flight Space Reactors was combined with Gap #3 – Storage of Test and Flight Space Reactors, because the activities related to the transportation and storage of test and flight reactors were determined to be similar enough to each other that they could be combined into one more concise collective need.
- Gap #6 – Facility Requirements for Testing was combined with Gap #5 – Testing Requirements for Space Reactors into Testing Requirements for Space Reactors, including Facility Requirements, because the facilities required for testing would be an integral part of the overall testing program and did not need to be considered as a separate gap with respect to the work of this SWG.
- Gap #9 – Methods to Calculate Radiation Doses from Space Reactors was combined with Gap #10 – Safe Operating Practices for Space Reactors, because the methods used to determine the direct radiation doses from space reactors are well understood and can be justifiably considered to be part of the determination of how to safely operate and work in the vicinity of space reactors.

After considerable discussion, Gaps #5, #8, and #10 were categorized as High importance, with Gap #8 ranking the highest.

- Gap #5, Testing Requirements for Space Reactors, including Facility Requirements was highly rated due to the perceived need to have guidance available on what testing can and should be conducted. Testing that would benefit greatly from standardization includes ground testing of components and full systems, pre-flight testing, launch preparation testing, pre-start testing and others.
- Discussion around Gap #8 concerning Safety and Risk Analysis Methods centered on standardization and maturity for this application of the methods and techniques used to analyze safety and risk. These analysis techniques appear to be well founded in their applications to other technologies, i.e., terrestrial reactors, probabilistic risk assessments, and others, and this area would be appropriate for the development of relevant consensus standards.
- The discussion of Gap #10 regarding the development of Safe Operating Practices for Space Reactors concentrated on observations that this area could be ready for consensus standard development. The identification of the choices of methods and analytical approaches seem to be well founded and available. This would include the methods and techniques used to calculate radiation doses from space reactors and the understanding of operational principles and practices of other nuclear reactors and their systems over the past five decades.

There are two gap areas that were determined by the SWG to fall within the Medium/Low Category, namely Gaps #3 and #11. Both of these gaps were considered to be of considerably less importance for moving directly into a consensus standards process. However, again, this does not imply that they should not eventually be considered in the future, just that they were of considerably lower initial priority as determined by the SWG.

- Gap #3, the Storage of Test and Flight Space Reactors, was determined to be not quite ready for consensus standard committee development at this time. It was discussed that too little was currently known about the individual designs of space reactors and there was too much variability in the applications of these designs to be able to appropriately develop effective consensus standards in this area.

- Also following a similar vein of conversation, Gap #11, the Decommissioning and Disposal of Space Reactors, was determined to not be ready for consensus standard development at this time. This will certainly need to be part of the discussion leading to a determination on the decommissioning and disposal of every reactor considered for use in a space mission; however, presently there remain too many variables (e.g., mission objectives, mission design, flight paths, operational envelopes, etc.) to be considered for the identification of effective consensus standards in this area.

Three gaps were identified in the Low Category, specifically Gaps #1, #2, and #7. Each of these gaps was deemed to not be currently ready or appropriate for consensus standard development. However, it will be important for one or more of the relevant agencies to focus on the further development of all three of these gaps at some point in the future, possibly through the development of an agency specific standard or handbook. Specifically:

- Discussion about Gap #1, Safety Design Process for Space Nuclear Reactors, was centered around the maturity of space reactor designs to enable the development of such a standard at this time.
- Gap #2, General Design Criteria for Space Nuclear Reactors, may not be technology-neutral enough at this time to enable a consensus standards committee to adequately establish a consensus standard in this area.
- Gap #7, Flight Certification or Licensing Process Requirements, does not appear fully developed enough to consider for passing on to a consensus standards committee at this time.

Table 2 provides a summary of the results of these discussions and characterizes the final ranking of the eleven primary gaps.

Table 2 Results of Prioritization of Gaps

Need	Gap	Title	Rank
a	#1	Safety Design Process for Space Nuclear Reactors	Low
b	#2	General Design Criteria for Space Nuclear Reactors	Low
c	#3	Storage of Test and Flight Space Reactors	Med/Low
d	#4	Transportation of Test and Flight Space Reactors	Subsumed into #3
e	#5	Testing Requirements for Space Reactors, including Facility Requirements	High
f	#6	Facility Requirements for Testing	Subsumed into #5
g	#7	Flight Certification or Licensing Process Requirements	Low
h	#8	Safety and Risk Analysis Methods	High
i	#9	Methods to Calculate Radiation Doses from Space Reactors	Subsumed into #10
j	#10	Safe Operating Practices for Space Reactors	High
k	#11	Decommissioning and Disposal of Space Reactors	Med/Low

7.0 Consensus Findings and Recommendations

The SWG believes that this study has been valuable and has identified important gaps where consensus technical standards can add value and should be pursued. The SWG has allowed relevant federal agencies to exchange ideas about the future of consensus technical standards as they apply to space fission reactor systems. All seven agencies play a role in some aspect of the space reactor system lifecycle. In assessing the priority of potential Voluntary Consensus Standards activities, the SWG determined that differing levels of knowledge about key practices and resources in particular areas influenced individuals' perspectives on the merit of standards development activities.

The SWG determined that interagency communication and knowledge sharing are key elements in gaining a common understanding of concepts and foundational in determining the most efficient and effective path to fill "gaps." While such communication and knowledge sharing start at the interagency level, the SWG believes that commercial stakeholders should be involved as soon as practical.

The SWG recommends that while the initial focus should be on the high-priority areas identified in this report toward moving those areas forward in the way recommended elsewhere in this report, the SWG concluded that topical areas that were prioritized as medium or low in this report would benefit from additional knowledge sharing that would help focus and perhaps, better define the priority.

The SWG identified four specific findings related to this study:

1. Consensus standards have value and should be pursued for space reactors.
2. An extensive review was conducted, and a list of relevant existing standards was compiled that should be a resource for future efforts.
3. Gaps that were not prioritized for near-term action are still considered important and could be topics for future agency-level guidance documents or community-of-practice workshops among member agencies to resolve the differences in the perceived gap significance.
4. The process used for standards development would benefit from broad participation by government agencies, stakeholders, consensus body organizations, industry, and academia.

The SWG has the following specific recommendations:

- The three gaps identified as high priority should be pursued through a consensus standards development process in the near term, namely:
  - Safety and Risk Analysis Methods for Space Reactors
  - Testing Requirements for Space Reactors, including Facility Requirements
  - Safe Operating Practices for Space Reactors
- An agency should be identified as the "Champion" for each of the three gaps to develop a work plan to define the next steps for each gap (including expected cost and schedule)

and engage other agencies and the appropriate consensus standards organizations, as appropriate.

- NASA should convene an interagency group periodically to review progress.

8.0 Conclusions

An interagency space reactor standards working group (SWG) was convened to address the lack of formalized processes to guide space reactor development and mission use. The SWG included representatives of seven federal agencies: Department of Defense (DOD), Department of Energy (DOE), Department of State (DOS), Department of Transportation (DOT), Environmental Protection Agency (EPA), National Aeronautics and Space Administration (NASA) and the Nuclear Regulatory Commission (NRC). A 6-month study was conducted to assess the need for consensus standards.

The monthly meetings that occurred between July and December 2021 produced four Findings and three Recommendations. The findings and recommendations were presented to the agency Standards Executives in January 2022. The next steps were put in motion to establish "champion" agencies for each of the three gaps and to engage the appropriate standards organizations.

9.0 References

1. Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems, The White House, NSPM-20, August 20, 2019.

2. Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities, OMB Circular No. A-119 Revised, February 10, 1998.

3. Principles for Federal Engagement in Standards Activities to Address National Priorities, White House, M-12-08, January 17, 2012.

4. Memorandum on the National Strategy for Space Nuclear Power and Propulsion, Space Policy Directive 6, SPD-6, The White House, December 16, 2020.

Appendix A

Appendix A
Letter from NASA Chief Engineer to Other Agencies

April 23, 2021

Reply to Attn of: Office of the Chief Engineer
Ms. Elise Owen
Mr. Colby Lintner
Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, DC 20460-0001

Ms. Louise Lund
Mr. Meraj Rahimi
Office of Nuclear Regulatory Research
11555 Rockville Pike
Rockville, MD 20852

Mr. Scott Clayton
Mr. Paul Najarian
Department of State
2025 E Street, N.W.
Washington, DC 20006

Dear Agency Standards Executives:

The Department of Energy (DOE), Department of Defense (DOD), and NASA are engaged in the development of space fission reactor systems to support a variety of proposed missions, including to the Moon and Mars. National Security Presidential Memorandum 20 (NSPM-20) Launch of Spacecraft Containing Space Nuclear Systems (August 20, 2019) specifies that the sponsoring agency is responsible for launch approval, and the Department of Transportation (DOT) is responsible for licensing commercial launches. The DOE has a long history supporting space reactor development and safety analyses for radioisotope systems and is a key collaborator for future nuclear space missions. The Nuclear Regulatory Commission, Environmental Protection Agency and the Department of State provide important support to ensure that our nuclear launches are safe and in conformance with international obligations.

However, despite a long and successful history of using nuclear systems in space, only one of those missions included a fission reactor: SNAP-10A launched in 1965. Thus, there are few standards or regulations in place specifically for space fission reactor design and safety. It is NASA's view that all agencies will benefit from the collaborative development of consensus technical standards in key areas. To that end, we propose to form a Space Reactor Standards Working Group and request your agency's participation. The first task would be to complete a study to validate the need for such standards, address any concerns that you might have, and chart a path forward. The attached proposal suggests two initial standards that may be of benefit to multiple agencies. We believe that these standards will enable compliance with NSPM-20, help ensure a consistent level of safety across programs, and reduce uncertainty in the nuclear system design process.

We request that you identify a civil servant participant to serve on a Space Reactor Standards Working Group and provide us with their contact information. We intend to limit membership for this study to federal agencies only. We expect to reference relevant studies and analysis being performed within the U.S. Government and may seek individual input from external subject matter experts at national labs, industry and academia. If the study concludes that a consensus standards activity is warranted, we will likely coordinate our findings with U.S. external consensus standards bodies.

Our preliminary plan is to convene the Working Group by June 2021 and complete the initial assessment by December 2021. NASA will provide a Working Group Chair and Secretary to organize the meeting sessions that would occur approximately twice per month. Participation by each agency will be voluntary with no expenses reimbursed by NASA. At the conclusion, NASA will host a meeting to review the Working Group findings and recommendations, and we would invite management representatives from the member agencies to attend.

If you have any questions regarding this activity, please contact Lee Mason from my staff at lee.s.mason@nasa.gov or (216) 977-7106.

We look forward to your participation in this important National-level interagency activity to facilitate the future use of space reactors.

Regards,

Ralph R. Roe, Jr.
NASA Chief Engineer
NASA Standards Executive
Enclosure

Identical letter to:
Mr. Garrett Smith
Mr. Jeffrey Feit
U.S. Department of Energy
19901 Germantown Road
Germantown, MD 20876

Mr. Michael Heaphy
Mr. Timothy Koczanski
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8725 John J. Kingman Road

STOP 5100
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Mr. Timothy Klein
Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

Appendix B

Working Group Meetings

Meeting #1, 19 July: Kickoff Meeting to review study scope, define operating principles, introduce members and collect inputs on work plan.

Meeting #2, 18 August: Member presentations on relevant existing guidelines and standards. FAA presentation on ASTM standards.

Meeting #3, 19 September: Invited presentation from DARPA on DRACO reactor safety plans. Finalize work plan and solicit expected needs from each agency.

Supplemental, 24 September: FAA presentation on commercial space launch and reentry licensing.

Meeting #4, 18-19 October: Invited presentation from Aerospace Corp on reactor safety. Extended meeting to finalize selection criteria, formulate gaps, and collect priorities from each agency.

Meeting #5, 18 November: Review final gap prioritization and draft report content.

Meeting #6, 16 December: Review draft report edits and draft Standards Executives presentation package.

Standards Executives Out-brief, 20 January: Final out-brief on findings and recommendations to agency Standards Executives.

Appendix C

Relevant Existing Standards and Guides

Summary of Most Relevant Available Regulations, Standards and Guides		
Owner	**Identifier**	**Title**
General		
NASA	NPR 7120.5	NASA Space Flight Program and Project Management Requirements
NASA	APL/NASA TSSD=23122 (2015)	Nuclear Power Assessment Study - Final Report
Federal Review and Launch Authorization		
NASA	NPR 8715.3, Chapter 6	NASA Space Flight Program and Project Management Requirements (Will be replaced shortly by a new Nuclear Flight Safety NPR)
Design (including Crew Safety)		
NASA	NASA-STD-3001 - Volume 1	Crew Health
NASA	NASA-STD-3001 - Volume 2	Human Factors, Habitability, and Environmental Health
DOE	DOE-STD-1189	Integration of Safety into the Design Process
NRC	RG 1.232	Developing Principal Design Criteria for Non-Light Water Reactors
ANS	ANS 6.1.1-2020	Photon and Neutron Fluence-to-Dose Conversion Coefficients
ANS	ANS 19.1-2019	Nuclear Data Sets for Reactor Design Calculations
Fabrication (including Assembly, Integration, and Ground Testing) of the Nuclear Device		
DOD	SMC-S-016	Test Requirements for Launch, Upper-Stage & Space Vehicles (2014) and associated tailoring SMC-T-011 (2017)
System Safety and Safety Analysis		
NASA	NASA/CR−2019-220397	Fission Reactor Inadvertent Reentry
DOE	DOE-STD-1237	Documented Safety Analysis for DOE Reactor Facilities
DOE	DOE-STD-1628	Development of Probabilistic Risk Assessments for Nuclear Safety Applications
DOE	DOE-STD-3009	Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses
DOE	HDBK-1224	Hazard and Accident Analysis Handbook

DOD	MIL-STD-882E	System Safety Program Requirements and associated tailoring SMC-T-004 (2019)
NRC	RG 1.203	Transient and Accident Analysis Methods
ANS/ASME	ANS RA-S-1.4-2021	Probabilistic Risk Assessment for Advanced Non-Light Water Reactor Nuclear Power Plants - ANSI/ASME/ANS RA-S-1.4-2021
ANS/ASME	ANS RA-S-1.2-2014	Severe Accident Progression and Radiological Release (Level 2) PRA Standard for Nuclear Power Plant Applications for Light Water Reactors (LWRs) - ASME/ANS RA-S-1.2-2014 (Trial Use Standard)
ANS/ASME	ANS RA-S-1.3-2017	Standard for Radiological Accident Offsite Consequence Analysis (Level 3 PRA) to Support Nuclear Installation Applications - ASME/ANS RA-S-1.3-2017 (Trial Use Standard)
NCRP	NCRP Report No. 171	Uncertainties in the Estimation of Radiation Risks and Probability of Disease Causation
ANSI/ANS	8.1-2014 (R2018)	Nuclear Criticality Safety In Operations With Fissionable Material Outside Reactors
ANSI/ANS	8.21-1995 (R2011) and R2019	Use Of Fixed Neutron Absorbers In Nuclear Facilities Outside Reactors
Launch Operations		
NASA	NASA-STD-8719.24-Annex	Annex to NASA-STD-8719.24 - NASA Launch Vehicle Payload Safety Requirements
DOD	AFSPCMAN 91-710	Range Safety User Requirements Manual Vols 1-7 (2004)
Flight Operations		
NASA	NASA/CR−2020-220569	Operational Considerations for Space Fission Power and Propulsion Platforms
NASA	NASA/CR−2020-5009307	Operational Considerations for Fission Reactors Utilized on Lunar In-Situ Resource Utilization Missions
NASA	NASA/CR−2021-0000387	Operational Considerations for Fission Reactors Utilized on Nuclear Thermal Propulsion Missions to Mars
Emergency Response and Radiological Contingency Planning		
NASA	KSC-PLN-1903	KSC Radiological Contingency Plan for Major Radiological Source Missions
NRC	RG 1.242	Performance-Based Emergency Preparedness for Small Modular Reactors, Non-Light-Water Reactors, and Non-Power Production or Utilization Facilities
ANS	ANS 3.11-2015 (R2020)	Determining Meteorological Information at Nuclear Facilities
ANS	ANS 3.8.6-1995	Criteria for the Conduct of Offsite Radiological Assessment for Emergency Response for Nuclear Power Plants

FEMA	44 CFR Part 351	Radiological Emergency Planning and Preparedness
ANS	ANS 8.23-2019	Nuclear Criticality Accident Emergency Planning and Response
EPA	EPA-400/R-17/001	EPA 2017: Protective Action Guidelines
ISO	ISO 16117:2013	Nuclear Criticality Safety - Estimation Of The Number Of Fissions Of A Postulated Criticality Accident
ISO	ISO 27467:2009	Nuclear Criticality Safety - Analysis Of A Postulated Criticality Accident
IAEA	Safety Standard GSR Part 7: 2015:	Preparedness and Response for a Nuclear or Radiological Emergency
FDA	Compliance Policy Guidance (CPG) Sec. 555.880	Guidance Levels for Radionuclides in Domestic and Imported Foods
Technology-Specific Survey Reports		
NASA	NASA/TM−105711 (1991)	Nuclear Thermal Propulsion Technology: Results of an Interagency Panel
NASA	NASA/TM−105707 (1993)	Summary and Recommendations on Nuclear Electric Propulsion Technology for the Space Exploration Initiative
NASA	NASA/TM−2010-216772	Fission Surface Power System Initial Concept Definition

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14. ABSTRACT
A U.S. governmental interagency space reactor standards working group (SWG) was convened in April 2021 with a memo from the NASA Chief Engineer to address the limited standards and regulations in place specifically for space reactor design and safety. The convening memo requested support from the Standards Executives of six other federal agencies. The Standards Executives agreed to support a 6-month study to assess the need for consensus standards and identified SWG representatives from each agency. This report summarizes the SWG's study, their findings, and their recommendations.

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